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USE OF CONCEPT MAPS AND WIKIS FOR EARLY ENGINEERING DESIGN AND COLLABORATIVE ENGINEERING

By

Janaka S. Weerasinghe, B.Eng

Ryerson University, 2005

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Abstract

“Use of Concept Maps and Wikis for Early Engineering Design and Collaborative Engineering”

Master of Applied Science, 2007

Janaka Sandun Weerasinghe, B.Eng.
Mechanical Engineering, Ryerson University

Concept Maps and wikis were examined as tools that compliment the engineering design process and better facilitate collaboration between geographically dispersed design teams. Concept maps are a visual knowledge capture medium that can be used to promote the understanding of the design problem and in providing an organizational reference for the entire project. Wikis are editable websites that give users the freedom to add content in any manner, thus providing a project management platform for design teams. This thesis reports on five studies by the author in which concept maps and wikis are used as both tools for the design process as well as collaborative tools in various modes of interaction. Recommendations to improve concept maps and wiki technologies were determined based on the feedback from the participants in these studies. The wiki was used extensively as a project management tool but required some push for the participants to use. The hierarchical layout structure has been shown to be the favoured pattern by participants in the engineering field. Concept maps are also shown to be a clearer visualization tool than another accepted tool, Unified Modelling Language.

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CHAPTER 1: INTRODUCTION

Advances in communication technology have brought people closer together regardless of distance. A simple peer-to-peer networking system like Facebook (www.facebook.com) allows someone to find a friend they knew years ago in kindergarten regardless of whether they are half way across the world. This power of technology has also allowed industry to evolve in the way it approaches design. Design teams are no longer limited by their geographic location in order to seek the best intellect for their projects. They can seek the active participation from experts in a particular field even if they are very far away. Understandably, this brings up a number of complications including: time zone differences, differences in engineering standards which may complicate the gritty details of a design, and cultural differences which may hinder the communication between groups. However, once these differences have been overcome the quality and capability of the design group is improved greatly.

Not only must a company now accommodate these distant experts, but the current philosophy for design promotes the active involvement from every level of product stakeholder [1]. This has created a demand for collaboration tools that can accommodate all these team members and focus the project. Before these tools were developed, wide spread teams would rely heavily on multiple forms of online communication like email, instant messaging systems, and file transfers that led to a lack of synchronization between the information stores and the participants. There was a need for one or two key tools that allowed groups of people to collaborate together in a community setting [2]. In 2004/2005 a survey was performed here at Ryerson University on manufacturing industries use of Project Lifecycle Management (PLM) software in their work [3]. The researchers found that a large number of respondents considered the design issues to be more important than the manufacturing issues and that more improvement and emphasis for such collaborative design packages should be placed on the conceptual design stage of the lifecycle.

This thesis will demonstrate how concept maps and wikis can be used as collaborative tools to help early engineering design. Concept maps are a specific type of web diagram that facilitates the exploration, gathering and sharing of ideas [4]. Wikis are

editable websites that can be customized to meet a number of collaborative roles.[5] Concept maps can be used as the tool to encourage higher level thinking in conceptual design while still working with wikis to bridge the gaps between these distributed personnel. The visualization would allow these teams to really see the scope of the data and how disparate datasets interrelate allowing them to make that insightful breakthrough [6]. By using a wiki to centralize all the requirements a design team will have all the critical information it needs to make the correct design decisions [7]. Since all the information on the wiki is stored on a server the only thing required to access it is a web browser. Thus wikis becomes a many-to-many knowledge creation model, as opposed to a one-to-many model, like email or web logs [8].

The majority of this research was centered on a project on collaborative design within the Canadian Network of Centres of Excellence *The Automobile of the 21st Century* (hereunder, the Auto21 project), which will be discussed in detail later on. The initial goal of the Auto21 project was to see the effectiveness of concept maps as the predominant method of collaboration, but as the project progressed the team began using wikis as for more of their collaboration needs. Thus this thesis will show the usefulness of concept maps and wikis as tools for collaborative engineering design with distributed participants.

This thesis will first show what concept maps and wikis are and how they can be used in the early stages of the engineering design process. The end of the early stages of engineering design shall be defined as all the design stages up to and including the systems design stage. The body of the research being presented will be an examination of 5 studies where concept maps and/or wikis were used in some form of collaborative exercise. The culmination of this work will be a list of recommendations that can be used to either improve current software or aid in the development of future concept mapping packages or wiki technologies

CHAPTER 2: BACKGROUND

2.1 Concept Maps

Concept maps represent a basic form of visualization that can be employed in any group discussion situation regardless of discipline thus making it a useful tool for preliminary design work as it can be used by all the participants from the engineers to the marketing staff to the customer. Concept maps can be used to portray a large amount of complex information making it easier to understand and see the interactions between concepts. Such a form of visual communication can be more immediate than text [9]. Novak describes concept maps as a visual roadmap to show pathway that connect concepts [10]. This makes the communication of that information easier since it is now in a structured form that can be easily assimilated. With this organized knowledge it is possible to answer focused questions about the content of the map [4].

Concept maps consist of *nodes* connected by *links*. A node is a geometric shape (usually a rectangle) containing a text fragment that represents a concept, idea, item, or question. A link connects two or more concepts together, and represents a relationship between the concepts. Links are labelled with a text annotation describing the nature of the relationship. Nodes in a concept map are often labelled with nouns interpretable as object names and arcs labelled with verbs interpretable as relation names [11]. This is usually done to help understanding as the flow becomes similar to full sentences, something people are readily familiar with [12]. The links can be unidirectional or bi-directional, depending on the nature of the relationship but the relationship must be explicit. A link that has no annotation shows a lack of understanding of the relationship between the connected nodes.

In order to achieve a higher level of organization, graphical properties of these elements can be changed. For nodes, the style can be altered to group common concepts by colour or shape or font of the node's text. For links, the style can also be altered to reflect various types of relationships between nodes, including line thickness, arrowhead style, colour, and style (e.g. dashed versus solid lines). Concept maps make no specific

commitments to what such style variations mean. Instead, one expects the user to establish conventions regarding style that are meaningful to the expected “readers” of the map. In a design setting this means that each user group of users have the flexibility to create their own norms when it comes to expressing knowledge.

Concept Maps have been used primarily in education as an assessment tool, not an evaluation tool [13-16]. Psychologists posit that the expertise in a particular field grows as the elements of knowledge become interconnected [17]. Concept maps are seen as a direct representation of the interrelatedness of knowledge elements [18]. Educators have been using concept maps to gauge a student’s understanding on a subject and how the student relates new material to what he/she already knows. Students would create diagrams to organize their current body of knowledge in a way that makes sense to them. When new knowledge is presented, the student can see how it can be integrated into their original web thus relating the new knowledge to existing knowledge and enhancing his/her understanding of the subject [19].

Elements of this learning process can be seen in the early stages of the engineering design process where members of design teams are trying to understand the problem that is before them. Understanding the design problem can be represented in an original concept map and all the work that is produced from each step of the process becomes new knowledge that they can integrate into this foundation. Successful capture and sharing of each member’s expertise depends on their ability to explain their knowledge and then represent it in such a way that it supports effective examination by other members [20]. It is this back and forth sharing of ideas and feedback that makes concept maps a viable tool for engineering design.

2.1.1 Novakian method of constructing a concept map

Novak describes concept maps as a framework of meaningful propositions each proposition being made up of two or more concepts connected by a link to form a semantic unit [21]. The concept map as a whole is created to present a body of knowledge of to answer a focused question. It is the topic or question that becomes the root of the map and all the subsequent propositions are developed from it in a hierarchical

pattern. The pattern would allow the more general topics to be formed at the top of the map while the more specific concept would be developed below.

Novak encourages crosslinks across branches of knowledge which helps the author see the interrelationship of concepts on different domains of knowledge. Such links are representative of deep and meaningful understanding of the subject being presented [10]. These two criteria are the essence of a good concept map

Layout within the hierarchical structures can have a significant impact on how information is captured. Novak discusses how the same set of concepts can be configured to any map pattern depending on the context of the map which plays an important role in determining which concept will be the focus of the map. As shown in Figure 2.1, each map consist of the exact same nodes but in the first map the importance is given to living things and what that concept entails, while in the second map the emphasis is placed on the molecule [4].

Figure 2.1: Context varying with layout configuration (created with CmapTools)

This is very useful for engineering design as it gives the team flexibility for situations where the focus of the design shifts from one requirement or constraint to another. The designers can reconfigure the map without having to start from the beginning.

A study done at the University of Massachusetts, [22] on concept maps in design shows that concept maps created would generally follow four major patterns, linear, web, branched and cat's cradle (Figures 2.2a and 2.2b). It showed that linear patterns tend to

represent a step-by-step relationship from one concept to another, but showed no interrelation between a number of concepts or a need to iterate the map to include new concepts. While the cat's cradle, branched and web patterns all showed more diverse connections between concepts, cat's cradle contained many additional links that lead to misconceptions about the concepts being discussed.

Figure 2.2a: Major layout patterns as discussed by Knight [22]

Figure 2.2b: Major layout patterns as discussed by Knight [22]

2.1.2 Other Mapping Techniques

Some other mapping techniques besides concept mapping are Unified Modeling Language (UML)/Systems Modeling Language (SysML), Structured Analysis and Design Technique (SADT). These techniques will be compared with concept mapping later on in this thesis.

Unified Modeling Language (UML)/Systems Modeling Language (SysML)

Unified Modeling Language is an object modeling language used to create a model of any kind of system. UML was created in the mid 90's in an effort to push the adoption of object-oriented technology as it was being stalled by the emergence of numerous modeling languages. Originally intended for software modeling, UML has now been adopted for business modeling and systems engineering (SysML) [23].

UML has 13 different types of diagrams that emphasize the *structure*, *behaviour*, or *interaction* of the system being modeled as seen in Figure 2.4. Each type of diagram showcases a specific area of knowledge and thus each has different layout structures.

With the specific information provided in each type of diagram, UML provides a structured model that can be understood by all participants.

Figure 2.3: UML Diagram Taxonomy

SysML is developed for engineering specifically and only uses a subset the UML diagrams. Developers hoped that systems engineering done using UML techniques would make for easy compatibility with any of the software models created using UML, thus improving communication between system and software personnel [24].

Structured Analysis and Design Technique (SADT)

Structured Analysis and Design Technique is a diagramming notation that is used to represent decisions, actions and activities of a system. This technique shows the functional perspective of any system or organization [25]. SADT diagramming uses the ICOM principle, seen in Figure 2.5, where each box represents an operation or function and the arrows around it indicate the interfaces with other operations or the environment. The resulting structure is a linear hierarchy of nodes flowing diagonally across a page. Each function can be broken down into sub-functions and shown in separate diagrams

with appropriate labelling to show where it is in the grand scheme. Thus a model of a system becomes a library of small diagrams that relate to one another

Figure 2.4: ICOM principle

In early engineering design there needs to be more freedom for the designer(s) to layout their structure in a manner that makes the information more meaningful for them. The four afore mentioned diagramming techniques have been created for their respective niches of visualization but these techniques are too regimented in their layout procedure to allow for variation in structure. Even though Novak has outlined several rules and conventions to creating concept maps there really are no firm syntactic rules and no formal rules of interpretation or semantics [11]. Thus concept maps are a potentially useful medium to explore how engineers visualize knowledge as they don't have any visualization constraints unlike the other techniques mentioned.

2.2 Wikis

Wikis are open websites where the intended audience of the site can freely edit the content of the site. The concept of a wiki is to allow the input of the reader in order to further elaborate and refine the knowledge being presented on the site. By allowing readers to edit the page, more "experts" in that particular field can contribute their insight

so that the community of readers can be better informed. This input enriches the knowledge being presented and makes it more valuable to outside readers. A wiki provides a single tool which can be incrementally developed by a group of collaborative users [26].

The key concept of a wiki is that it provides an open space for people to add information to the site without having to be proficient in web space programming. Authorized users can access a text editor on any of the wikipages and begin adding their opinion onto the text space. Most of the text editors require a certain amount of learning to become familiar with the syntax. Every wiki has a unique syntax that allows the author to perform certain formatting functions like bold, italic or bulleted lists. This has provided a hindrance to the adoption of wikis since there is no universal standard for wiki syntax that can be applied to all wikis. Due to the unfamiliarity of the syntax it takes a while before a user is fully comfortable with using a wiki text editor. To counter this problem wiki developers began including WYSIWYGs ("What You See Is What You Get," pronounced wih-zee-wig) which are text editors that have a familiar word processor feel to them. The concept here is that the edit space is an exact representation of what the rendered wikipage will be. However, this is not always the case as there remain subtle but sometimes significant differences between the renderings in the WYSIWYG editor versus the final page.

Since most wikis are open source, there is no "capital" financial burden on companies to set up the wiki. The burden comes in setting up the wiki, as it can take some time to customize the wiki to perform the desired functions, and to train new users.

2.3 What is Early Engineering Design?

"As a project progresses through the different stages of a product life cycle the cost of making changes to the design rises exponentially. So it is critical that all the correct decisions are made in the preliminary design phase" [27, pg 47]

Part of the focus of this thesis is on how concept maps and wikis may help engineers in the early stages of the engineering design process. This section will discuss at what point in the 'early' process ends.

The engineering design process has evolved in recent years due to advances in technological resources that are now available, i.e. CAD drafting or rapid prototyping, but the preliminary design phases still remain the same. This section will explore the stages of engineering design as approached by Pahl and Betz, Otto and Wood, Burger, and Salustri (which is based on Pugh's Total Design with elements of Suh's axiomatic Design and Dym/Little's Method) [28-31].

Task Clarification and Specification

Before any conceptualization can occur there must first be a clear understanding of what the problem is. The task clarification will allow the designers to confine their thinking to answer specific questions pertaining to the essence of the problem. Burger's approach uses abstraction to determine the 'real' problem. He takes the initial problem statement and questions each aspect of that statement to see if they are truly necessary in addressing the heart of the problem. This reduces the statement from a colloquially expressed statement into a functionally precise definition using technically fundamental terms [29].

Understanding the problem is not limited to the product itself but also the broader factors of how it will fit into the market and how much it will cost. Salustri (2007) uses a Product Strategy to force the designers to make important decisions about aspects like target market, degree of innovation, complexity of design, and ease of manufacture. [31] These considerations will slowly begin to focus the mind of the designer into the design space within which the product will be conceived.

Once the problem has been clearly identified the designers can start considering the customer needs along with the product strategy to identify the functional requirements. Pahl and Beitz approach creates a specification list that distinguishes each requirement as a *demand* or a *wish*. *Demands* are requirements that have to met under all circumstances. Failure to meet any of the demands results in an unacceptable design. *Wishes* are items that the group should try and consider when conceptualizing the design.

Salustri's method uses a Product Design Specification (PDS) to emphasize the designers understanding of the problem and how the solution will address the problem. The PDS starts with a look at the product characteristics (PCs) which are properties that the product must embody, commonly describes as what the product must *be*. In order to satisfy each PC there may be one or more functional requirements (FR). These describe what the product must *do* in order to achieve its ultimate purpose. From here any constraints (C) can be associated the appropriate FR as it puts a limit on how well that function can be performed. Now performance metrics (PMs) can be used to test how well the design performs. The PDS is represented in a visual medium so that all the interconnectivity of PCs, FRs, Cs and PMs can be seen. Figure 2.6 shows the PDS of a landmine detector, developed by the author, to be created and run by third world nations. From the diagram there is a clear indication as to the purpose of the landmine detector and the functions that it must meet in order to achieve that purpose. Not only is there consideration of the direct role of the product but also the place where it will be used and the people that are going to use it.

Figure 2.5: PDS of Landmine Detector (created with CmapTools)

Concept Generation and Selection

The designers can now use all the information they have gathered in the previous section to come up with possible concepts. Each concept is evaluated based to see which concept best meets the predetermined requirements. At this stage designers can modify or combine concepts in order to find the concept that meets all the requirements. When a winning concept is decided on the designer then moves to a system identification stage to design the subsystems of the product.

System Identification

Once all the functional requirements have been identified a product architecture is created to map out the order in which each function is performed to achieve the over all purpose. Pahl and Beitz and Otto and Wood methods use function structures to show the inputs and outputs from one function. This outlines the flow of every kind of mass, energy and information through every subsystem connecting everything into one cohesive design. With this designers can see what systems are needed to perform these functions and what the possible interfaces of the systems are.

The next few steps of the design process vary depending on the product. With the advances in design mentioned before many products are modeled in simulation software or CAD packages so that the designers can see how the virtual models will react to simulated scenarios. Usually a prototype would be created in order to test out and verify that the design meets all the requirements outlined at the onset of the project. The prototype is tested with real world scenarios and feedback is gathered from the target demographic in order to optimize the design. Once this is complete there would be a move toward a plan for mass manufacture. For this thesis we will consider the 'early' stages of design up to the creation of system architecture of the product.

2.4 Collaboration

Collaboration is defined as two or more parties working together to achieve a common goal [32]. Such an endeavour requires the sharing of knowledge and a consensus of items being collaborated on. Collaboration can take many modes of interaction depending on the time and place that it occurs as shown in Figure 2.7. [12]

Figure 2.6: Interaction Modes for Collaboration (created using Dia)

Asynchronous Remote Collaboration

For many design teams that are geographically distributed the opportunity of synchronous collaboration is limited. Traveling to a common meeting point is a tedious, time consuming and often expensive endeavour. Using mediums like video conferencing and telecommunications is an effective substitute, but with far spread groups there is a time constraint on any collaboration. With greater distance there is a larger gap in the

time zone difference between locations and so the window of opportunity to do synchronous collaborative work is reduced. [33]. This is where design teams rely more heavily on asynchronous collaboration methods to compensate for their inability to work together in real time

Synchronous Collaboration

For face-to-face meetings to be effective there has to be that visual medium that gives the group a point of focus. This can give everyone a sense of what has been accomplished so far as well as an idea of the amount of work that has yet to happen. Using a visual aid is similar to a lecturer using a slide presentation to keep an amphitheatre of students captivated. With the visual aid the whole group has a concrete idea of what the meeting is about and so is more open to contribute instead of holding back due to uncertainty.

Synchronous Remote Collaboration

One of the basic ways to collaborate is distributed synchronous collaboration where participants from various locations work together on a certain project in real time using a number of communication tools. Using only asynchronous collaboration is inadequate to generate a group environment, there has to be real time collaboration and discussion [34]. Thus engineering design teams are now using various methods, like audio/video conferencing, over the internet in real time to simulate on site meetings. Concept maps can be used in this collaboration scenario to allow a distributed group of designers to focus on a single map that would represent the bulk of their work.

Group Dynamics and Emergence of Roles

Beyond the method, collaboration is also dependant on the group dynamics. It requires that everyone understand and fulfill their obligations [35]. At times individuals will seek to assert dominance in an effort to elicit submission or compliance [36]. Pena shows that in geographically distributed teams there is a higher tendency for dominance perceptions than in collocated groups [37]. In an exercise that was run by Komis at the University of Patras [38], a number of students were put through a program in order to

explore how students collaborate using concept maps. Research showed an emergence of roles where some students would dominate the group interaction. The Patras exercise also introduces the concept of a 'key' to control the input of the participants in a synchronous collaborative concept mapping session. This is similar to Edwards's proposition of varying access control for different roles within groups [39]. The personalities of the group members and their interactions with each other play a role in the way they collaborate, regardless of the tool.

2.4.1 Concept Map Collaboration

The majority of the work regarding collaboration with concept maps has been used to see how it contributes to collaborative learning among students [40, 41]. Stoyanova and Kommers found that "shared" concept maps were an effective way to collaborate synchronously for distributed groups [42]. Concept maps have been used as a visual medium to guide face-to-face meetings. In 2002, Dumestre, a representative of the US Navy worked in conjunction with IHMC to make Job Task Analysis (JTA) workshops more efficient using concept map in face-to-face sessions [43]. JTA workshops are intense sessions where personnel review and analyze all the areas in the navy that require personnel and then determine the job requirements and skill levels for each position. The participants of the JTA workshop found that the work progressed much faster using the concept map than with the previous method. With the large visual reference the participants were able to quickly make a comprehensive list of all the necessary data and then more easily find the connections between them.

2.4.2 Wiki Collaboration

Wikis can only facilitate an asynchronous mode of collaboration whereby many people can edit wikipages at any time and from any place. Due to its open nature a wiki can take on a variety of roles. Most often the wiki is used as an information storage depot where authors would record information that is accessible by everyone to view and

comment on. Information can be added directly to the wiki page through the text editors or can be attached to the page (useful for images and non-wiki format documents).

Another popular aspect of wikis is the ability to support discussion (as with email “mailing lists”). Some wikis, like *Wikispaces* [www.wikispaces.com] come with their own discussion sub-pages for each wiki page. This results in a forum style, where the discussion page would show a list of all the discussion threads that are organized by context. Even if there is no discussion option, the wiki is versatile enough that a page can be converted into a discussion board with each thread having its own wiki page.

One of the more familiar wikis is *Wikipedia* [www.wikipedia.com]. This encyclopaedic wiki has rapidly become a resource for many people for quick information on various topics. It has grown in the breadth of topics it covers as well as the depth of knowledge in each item due to the constant contribution by the general public. At first glance there may be a lot of scepticism about this method as there is a high potential for mass misinformation since there is no way to verify the subject authority of the authors. Yet Wikipedia has been rated almost as accurate as the Encyclopedia Britannica [44] which highlights nature of a wikis in that if someone posts a piece of information that is incorrect there are others that will come in and correct it [45].

For large projects, a wiki can be used as a project management tool since everything pertinent to the project is localized on one medium. This makes it easier to track progress, but more importantly it gives a better idea of points of lag and thus allows project leaders a chance to delegate responsibility to make up for the lag. Some wikis, like TWiki (www.twiki.com), provide specialized “plug-ins” (like timelines and workflow packages) to support these activities.

TWiki has been used as a project management tool by a number of industries [46, 47]. Developers at Cingular Wireless have used the wiki as a way of collaborating by combining their knowledge to a few wiki pages that allow them to better improve their in house processes [48]. Texas Instruments began using a wiki in 2003 to help manage some of their design groups [49]. They would use it as a common place to put all their relevant data so other groups can have access to the information. Even when there was a push for more commercially available tools like Share Point, a PLM tool, the users found that the wiki was able to better meet their collaboration needs.

CHAPTER 3: CONCEPT MAPS IN THE DESIGN PROCESS

Engineering design can be challenging and exciting, or it can be taxing, difficult and unproductive [28], but by implementing a process that highlights the creative and challenging aspect of design it may encourage a designer to pursue a more innovative product. Concept maps can be used as a medium to foster this creative aspect in the design thinking while still reducing the hindering moments.

As described earlier, most of the models for engineering design can be described as having three broad stages; Understanding the opportunity, developing concepts, implementing concepts. Naturally each of these stages have a number of sub-stages that a designer must perform, but many of these steps can happen concurrently thus making the process more complex. In a broad scheme concept maps can be used as an organizational/task management tool to ensure that everyone is aware of the ‘big picture’ and can track the current status of the project. Beyond this task concept maps can be used in some of the design stages to make them more productive. This section will see their implementation in the *Task Clarification and Specification* and *System Identification* stages.

3.1 Task Clarification and Specification with Concept Maps

The initial stage of any design process requires a thorough examination of the design space in which the product is to be used. A designer has to outline a number of different factors before exploring the inner workings of a product. These factors deal with the marketing and business aspect of any product development, sometimes referred to as the *fuzzy front-end* due to the level uncertainty at that stage of the project [28]. Looking at things like the target market, degree of innovation or complexity will give the designer a sense of the actual purpose of the product being designed. These items are discussed in detail during a collaborative process between designers and clients where requirements can be negotiated [34].

At this stage of the design process there is a large amount of brainstorming activity where all the ideas are brought up so that they can be considered. With a concept map all the points can be placed into the map space and then easily grouped into common categories. Concept maps are useful for creating the PDS diagram from the Salustri method. Traditional implementation of this process requires writing all the items out in separate lists. Once the lists have been exhausted, the items are then combined into one diagram which has similar properties to a concept map.

In organizing all the information into a PDS format there is a more visual overview of the product as a whole. This gives the designer the chance to see areas that may be in need of further investigation (i.e. a lone product characteristic). In Figure 3.1, which shows the PDS of toaster it is clear that the marketability of the toaster hasn't been fully developed. With that in mind we can now add to the PDS and further link it to what is already established about the toaster design to create an updated PDS as shown in Figure 3.2.

Figure 3.1: Product Design Schematic (PDS) of a Toaster (created with CmapTools)

As the design evolves through the design process the PDS also evolves to accommodate new design decisions. With the concept map new ideas and requirements can be quickly added to the PDS so that their implications to the whole design can be easily determined.

Figure 3.2: Refined PDS of Toaster (created with CmapTools)

3.2 Systems Design Stage

Systems design involves the identification of the elements that exist within a product that work together in order to meet the product function. In order to understand the transformation done by each system it is important to know all the inputs that are available to the system and what outputs are produced. The PDS provides a guideline as

to what function each subsystem will perform by showing what the expected outputs of a system should be. With this knowledge the designer can create a Product Architecture Schematic (PAS) which outlines the functional path of the entire product.

Concept maps can be used to create system architecture diagrams where the systems would be represented as nodes and the link between them would be the interface. Since the link styles are variable it is possible to represent the flow of mass, energy and information throughout the system as seen in the architecture diagram of the toaster in Figure 3.3.

Figure 3.3: Architecture of a Toaster (created with CmapTools)

Instead of a PDS, another design method is a functional flow block diagram, which is essentially a linear concept map, to show the sequence of occurrences from one function to the next, similar to a function structure used in Pahl and Bietz. Using a function flow block diagram allows the designer to ensure that there is a system performing each of the required functions. Based on the functional flow block diagram it is easier to determine the systems for the product since the order of operation is known. Using the FFBD in Figure 3.4, a system architecture was able to be created to match the process outlined (Figure 3.5). This architecture schematic clearly shows the flow of mass, energy and information via the use of different line styles. More importantly, the

common elements of the design were able to be grouped together to identify subsystems of the entire lander.

Figure 3.4: Functional flow block diagram of Mars Lander (created with CmapTools)¹

¹ Image created by students in W2006 AER817 class for the design of a Mars soil retrieval system

Figure 3.5: System Architecture for Mars Lander (created with CmapTools)²

² ibid

CHAPTER 4: STUDIES OF CONCEPT MAPS AND WIKIS

Before discussing the studies conducted in this thesis it should be noted that while this paper is looking at the ways engineers collaborate with wikis and concept maps there were no practicing engineers involved in this study. All the participants were university students and professors predominantly in engineering fields. The lack of participation of practicing engineers in academic research is an on going dilemma and has even prompted some researchers to propose facilities that would be dedicated to just gathering data on how real world engineers conduct themselves [50]

The five studies in this thesis are the Auto21 project, the ME8101 study, St. Michael's Hospital study, CIHFR study and the CDRN concept mapping workshop. Each study looks into specific aspects of either wikis or concept maps, and their applicability as collaboration tools for early engineering design

4.1 Auto 21

A large portion of the work being presented in this thesis is done as part of The Automobile of the 21st Century (Auto21), a national initiative undertaken within the Canadian Network of Centres of Excellence and helps to fund various research projects pertaining to automobiles design and development [www.auto21.com]. The goal of Auto21 is to create a research community that enhances the profile of Canadian innovation on the global automotive stage. Research projects vary in theme from exploration of new materials to safety analysis to social effects on the community. A specific theme is dedicated to the design process among which is an interest in collaborative design methodologies and tools for design teams.

One of the many projects is a multi-university endeavour that is looking into understanding how engineers collaborate in the early stages of a design process. Graduate students (also referred to as HQP, Highly Qualified Person) and their supervising professors (also referred to as PIs, Principal Investigators) from a number of universities across southern Ontario formed a team to design an environmentally friendly urban vehicle. Each student brought a different engineering expertise to the group

allowing for an easier division of tasks making each school responsible for one sub system of the vehicle. It is important to realize that the design of the car was just a medium from which to observe and analyze how collaboration was taking place within this engineering design team that were geographically separated.

4.1.1 What was done?

Since the goal of the Auto21 project was to explore how engineers in a distributed setting would collaborate on a design project, the design team was given a number of tools with which to collaborate while designing the urban vehicle. The tools were:

- **Concept maps**, using CmapTools and CmapServer. Concept maps were a new medium for most of the participants. A few of the PI's had used concept maps before but not in a collaborative sense, just as a visualization tool. The server facility for CmapServer was done at Ryerson University.
- **Team Centre Community (TCC)**, a product lifecycle management (PLM) package that is used by many engineering industries. This medium was new to many of the team members. The server facility for this package was setup and monitored at Waterloo University
- **TWiki** a wiki was set up as an online space for all the students to be able to report on their progress. Few of the participants, PI's and HQP, were familiar with wikis but none had used one as a collaborative tool for a large project. The server facility for the wiki was done at Ryerson University as well.

Participants were discouraged from using email or instant messaging services as a means of discussing the project since there was no easy way to keep track of the collaboration taking place. With CmapTools, TWiki and TCC all the collaboration was recorded. Feedback for all the collaborative tools being explored was gathered during face to face discussion sessions as well as questionnaires that were posted on the TWiki for everyone to view and comment on. The concept maps produced during the project and the feedback given about the usage of concept maps were examined to determine if the diagramming technique was useful for the design process being used by the Auto21 group. From the written feedback on the TWiki about wiki and TCC as well as

observations on how the wiki and TCC were used, both platforms were compared to see which suited the needs for this particular design team as well as reveal important requirements for collaboration.

4.1.2 How concept maps were used?

Concept maps were used mostly in the preliminary planning stages of this project. Over the first few months the participants created a series of maps where each new map including new information and ideas as the project progressed. The collection of maps was examined for progression of content and choice of layout.

4.1.2.1 Analysis of concept maps in Auto21

Following the initial meeting where concept maps and CmapTools were introduced to the team, each member began to create concept maps that represented an outline of what they thought the project was going to be about. From an instructional point of view this exercise would be important as it showed the variability of understanding that each person had regarding the content of the meeting. Each concept map that they created would represent their point of view and so exploration and analysis of the differences in the maps may provide insight into how things were presented and interpreted. For the purpose of this project, which was a focus on collaboration, having each member produce their own map on the same material was inefficient and unnecessary. Even though each map was unique in terms of structure there were a lot elements and content that were the same. Thus creating a redundancy as there were many maps with the same information, as seen in Figure 4.1. Both maps show the basic goals of the project, a look at vehicle concepts, potential research topics and the education of HQP. There was no new knowledge being fostered. If everyone had added their viewpoint to the same map it would be a more accurate and comprehensive representation of what the project was about.

Most of the maps created for this project were by the principal investigators. The reluctance by the students to use concept maps was not because of the complexity of the CmapTools software, but more so due to an uncertainty of how to use concept maps for

designing. Many had never used concept maps before and didn't see its potential beyond a notion of a flowchart. Students were also unfamiliar with the idea of editing someone else's work and so there was a reluctance to edit existing something that wasn't their original work.

Figure 4.1: Two concept maps from the initial stages of Auto21 showing redundancy of information (created by Auto21 Group with CmapTools)

As people became more accustomed to the features of the software and the use of concept maps in general they began to create new maps based on the information presented in previous maps. This showed progress in the vehicle design aspect of the project as new ideas and information were being brought to the attention of the group.

Unfortunately this was not an effective use of concept maps as now there were multiple maps that had obsolete information and so became unnecessary. Again, the more effective method would have been if the users had built on existing maps and developed them further instead of creating new maps. This allow everyone to see how new concepts meshed with existing ones and gave a better idea of the ‘big picture’.

Looking at Figure 4.2 we can begin to follow an example of the evolution of a concept map. This figure shows one of the first concept maps that were created at the onset of the Auto21 project. Most of the concepts are very broad and there is not a lot of depth to the content but the general ideas of the project can easily be understood with a short browse of the map. Even with the lack of content there is still a clear indication that the project has two main components to it being the design of the vehicle and the exploration of collaboration.

Figure 4.2: Auto21 overview version 1 (created by Auto21 Group with CmapTools)

The next generation of the concept map is shown in Figure 4.3. This map was created a few months later and shows the identification of various subsystems as well as the addition of new concepts that were found to be relevant to the project. The two areas of interest, ‘Vehicle Design’ and ‘Research’, that were seen in the first map have now been more clearly defined by sub concepts. Under ‘vehicle design’ are all aspects of the vehicle that the designers have to take into consideration including design requirements, functionality and performance constraints. On the ‘Research’ stream there is a break

down of the various areas of research that the team will look into based on the expertise of the schools contributing to the project as well as methods of collaboration that can be explored in order to achieve one of the overall goals of the project. While this map has a lot more content, the structure and layout are no longer conducive to quick assimilation of the knowledge being presented. There is a definite hierarchical pattern to the progression of concepts as they become more defined through subsequent nodes in the map.

For 'Vehicle Design' the nodes begin to describe the aspects for designing the vehicle followed by an outline of the design limitations. The 'Research' stream looks into the various avenues of research from this project that may be of interest to the professors overlooking this endeavour. Even though there seems to be a hierarchy there is little about the layout to highlight this successive nature.

Figure 4.3: Auto21 overview version 2 (created by Auto21 Group with CmapTools)

The third iteration of the map seen in Figure 4.4 clearly identifies both streams of the project and emphasizes the inherent hierarchy layout pattern. By adding color to

each stream this further isolates each aspect of the project making it easier for a viewer to see which concepts belong to which stream. A concept map like this has advantages over text based representations, like bulleted lists, because the layout and links show inter-relations between the nodes that can not be captured in a list.

Figure 4.4: Auto21 overview version 3 (created by Auto21 Group with CmapTools)

Taking a closer look at the 'vehicle design' stream in Figure 4.5 the items highlighted in blue are clearly product characteristic, ideas that the product must embody like being affordable or environmentally safe while the elements shown in yellow outline the constraints that the designers have put on the vehicle. From the layout of these items we can see that the product characteristics were higher up in the map suggesting

that they were considered first along with market strategy considerations, like 'target market'. This was followed by consideration of the functional requirements and constraints as they are located lower down on the map.

Figure 4.5: Iteration of Side branch of Auto21 Overview 3, emphasizing design criteria (created by Auto21 Group with CmapTools)

Figures 4.4 and 4.5 show the considerable effort put towards the vehicle design aspect of the project as there is a large amount of detail added from the first iteration to this one. Yet nothing has happened on the 'Research' side of the project. None of the broad topics seem to have been developed since the previous map showing a disregard for that part of the project. This could be attributed to the early push by some of the PI's

to focus on the vehicle design and so the research part of the project became a smaller consideration.

Currently the Auto21 project is using concept maps to act as a guide for part of a wiki, one of the other collaborative tools that the Auto21 group, whereby all the relevant information regarding the progress of the project can be recorded. The wiki (which is discussed further in SECTION 4.1.3) acted as a common place where all the participants can go and showcase their work as well as provide discussion on any of the subsystems pertaining to the vehicle. In the summer of 2007, the group decided to focus on the suspension system of the vehicle and so a concept map was created to outline the basic areas of concern for the subsystem, see Figure 4.6. The map consisted of a background schematic of the suspension subsystem with nodes that pointed to the various parts within the suspension design. Each node would have a link to a corresponding wiki page where all the relevant information and discussion about that part would take place. This format for the map was suggested by a PI in one of the face-to-face meetings and seemed to receive enthusiastic support from the rest of the group.

Figure 4.6: Suspension project for Auto21 (created by Auto21 Group with CmapTools)

While the map created does not follow the traditional features of a concept map it does provide an example of how concept maps can be used as a visual guide. Without

the concept map the group would only have a list of links to use in order to follow the progress of the subsystem. An image like Figure 4.6 shows the ‘big picture’ of the design and gives an element of organization.

4.1.2.2 Webmaps

TWiki, the wiki being used, has an added plug-in called ‘MapThisWeb’ which generates webmaps of the wiki space around the page that the plug-in is used. When this function is called in the text editor of a specific wiki page it generates a graphical representation of that page and all the pages that it links to. Each node of the webmap represents a wiki page and is rendered with the page title in the node. This function is used to show the interconnectivity between all the pages within the wiki web. For the Auto21 wiki the web maps were generated for the vehicle subsystems to see if there was any interrelation between them.

The level of interconnectivity gave an impression of how people working on various subsystems were collaborating with each other. If a particular system was isolated this would mean that either no work was being done on that system or that the people responsible for it were going ahead without consulting the rest of the group.

Unfortunately there are many limitations to this function as it provides only a very basic representation of the information. The structure that it provides is purely hierarchical in nature so pattern groupings cannot be gleamed from this. Also it only provides nodes in one style, green in an oval shape, which doesn’t allow for a distinction between nodes pertaining to a certain subject. One of the other drawbacks is that it doesn’t allow the link between nodes to have any annotation so as to describe the relationship between the two pages. In terms of order, all the nodes in each tier of the hierarchy are listed in some semblance of alphabetical order based on their link to a node in a higher tier, again showing a limitation on the part of the function to group nodes based on the subject. An example can be seen in the Vehicle Design map, Figure 4.7, which is a webmap created from the ‘Vehicle Design’ page of the TWiki. This particular page was used because it was a jumping off point to all the other subsystems pages. From this figure it can be seen that all the discussion nodes are scattered across the third tier as opposed to being grouped together based under a common title.

Figure 4.7: Webmap of all the pages connected to the Vehicle Design wiki page using 'MapThisWeb' feature (Created by Auto21 Group)

4.1.3 Use of wikis in Auto21

The wiki has become the backbone of the Auto21 design project in that the majority of the design information and interaction can be found on this site. Since the project had the involvement of a number of schools the natural division of labour saw each school claim responsibility for a subsystem of the vehicle. The subsystems were chosen based on the expertise of the PI and the interest of the students.

Once it was decided that a wiki would be one of the collaborative tools that the team would explore a simple wiki called *Oddmuse* (www.oddmuse.com) was set up to allow the participants to become familiar with the usage of wikis while the main wiki, *TWiki*, was being setup. *Oddmuse* was the first exposure to wiki editing for many of the team. Usage on *Oddmuse* was very limited with most of the work contributed on to *Oddmuse* was by the principle investigators and not by students. Once the project was switched to *TWiki* there was more traffic. With *TWiki* the design team was able to designate a separate wikipage for each subsystem of the vehicle. As each group would progress in their research and design on their assigned subsystem they can post their findings on to the wiki so that everyone can view them.

In systems design, once the subsystems have been identified, it is important to determine the inputs and outputs of each subsystem so that the interfaces between subsystems can be established. With the *TWiki* centralizing all the information each group can easily find the information about various systems on their respective wikipage. This would foster discussions between the groups about the interfaces.

TWiki allowed for a number of plug-ins that could be added to the site giving more flexibility in how the participants present their research. One of the more used plug-ins with the Auto21 participants is the *Editable Table*. This plug-in allowed the author to create a table using the text editor, but once rendered certain cells were free to be edited by any authorized user. In the rendered version of the table there was an option to 'Edit Table' which creates the editable version of the matrix. The author could designate which cells are to be open to edition and which are to be constant. One of the high points of this feature is that once the initial table is created there is no need to go back into the text editor and hunt through numerous lines of code to change anything on

the table. This feature is useful for the designer as it allows them to create tables that allow all parties to contribute to design variables of the project. For Auto21 this was seen specifically with the *Mass Total* and *Vehicle Specification* tables.

The *Mass Total* table (Figure 4.8) was created as a pseudo mass budget of the vehicle. As each team would develop their subsystem they would include the rough estimate of how much it would weigh. As a new item was added to the tables the *Last Changed* and *Changed by* fields would be automatically updated allowing the other users to know who made the update and how recent the update was. This edition also gets recorded by the *Changes* page and so a notification email would be sent out as well as an update in the RSS feed. The sum total of all the weights can be shown using a single line of extra code below the table. This value is automatically updated whenever new items are added to the table. While there are some limits on the complexity of the calculations that can be performed by similar operations, the kinds of calculations needed in early design stages are usually quite simple. With a continuously evolving table like this, the team would have a good idea of the magnitude of this important variable in their design.

Mass Totals

BIG ASSUMPTION ABOUT COORDINATES!!!! (comments & revisions welcome)

- Origin is on centreline at front of car, on the **ground**.
- X axis points towards the driver's side.
- Y axis is down the length of the car.
- Z axis points up.

Parameter	Mass (kg)	CG x (mm)	CG y (mm)	CG z (mm)	LAST CHANGED	CHANGED BY
Motor Fore Left	40	500	200	150		
Motor Fore Right	40	-500	200	150		
Motor Aft Left	40	500	1700	150		
Motor Aft Right	40	-500	1700	150		
Chassis	1300	10	1000	200		

The following **TOTALS** are automatically calculated:

- **TOTAL MASS:** 1460 kg
- **CENTRE OF GRAVITY:**
 - **X:** 8 mm
 - **Y:** 994 mm
 - **Z:** 194 mm

Figure 4.8: Mass Table using *Edit Table* feature of TWiki

An editable table would be useful for pairwise comparisons in the concept selection stage of a design process. With all the product characteristics laid out on each of the axes, the users would just have to populate the cells with their decisions. Once complete the ranking of the concepts would be done automatically. If the user should change their mind about a certain characteristic decision they need only re-edit the table, again without having to use the text editor. One of the other TWiki plug-ins available is a polling feature. It would be useful at this stage to get the opinion of all the group members when choosing one characteristic over another.

The *Vehicle Specification* table, Figure 4.9, allows for a quick overview of the important parameters of the design without having to go to each systems page separately. By keeping the parameters of all the systems in one place there is a greater opportunity to see parameter groupings. The table on the left shows all the design parameters for that specific system and their current value. With the table on the right the group members can provide comments regarding any of the values expressed in the table on the left. Even though everyone has the ability to change the elements in the table on the left, there is an understanding among the group members that any editions will be made solely by those in that system group.

Suspension System

RELATED PAGES: [Suspension Discussion](#)

CURRENT PARAMETER VALUES				CHANGE REQUESTS LIST				
PARAMETER	CURRENTLY	AS OF	BY USER	PARAMETER	REQUEST BY	AS OF	PRIORITY	REASON
Upper Control Arm Front/Rear	0.9 kg	2006/08/16		Final Hardpoints	Queen's University	2006/08/04	DONE	Confirm final chassis configuration/dimensions.
Lower Control Arm Front/Rear	2.1 kg	2006/08/16		Weight Estimates	Queen's University	2006/08/04	DONE	For inertia representation of wheel package in crash simulation.
Upright Wheel Front/Rear	2.3 kg	2006/08/16		moment of inertia	Uni. of Waterloo	2006/08/16	DONE	would you please creat a table for the moment of inertia inputs. This table should have four columns: one for the part's name and three for the moment of inertia's of the parts in each direction.
Tie Rods Front	0.75 kg	2006/08/16						
Control Arms Rear	0.75 kg	2006/08/16		anti-roll bar	FilSalustri	2006/08/21	URGENT	On behalf of Farouk (see Suspension Discussion), the rationale for the anti-roll bar needs explanation/rationale.
anti-roll bar	1.2 kg	2006/08/16						

Figure 4.9: Partial capture of Vehicle Specification Table in TWiki

The wiki can also be used in the conceptual stage of the design process. Each concept can have a separate page where the author can give a brief description of how the concept works and include the sketch of the concept which can be added as an attachment to the page. This will give the members of a design team the opportunity to view each concept and comment on what they like or dislike about it.

As the Auto21 project progressed beyond the preliminary design phases and into a detailed design phase there was a shift from needing to share ideas and documents, to having to share CAD files and simulation data. At this stage the conceptualizing of the product was finalized and all the emphasis was put on systems design and integration of parts. The students would be using CAD models of their subsystems to test structural integrity as well as verifying system assembly, while other students would be running various simulation software to show drive characteristics. Many students shied away from the wiki when it came to these complex packages since the amount of data needed to share was too big. They would still use the wiki to post progress reports on results gained from simulations of image files on the current state of the CAD design, but the updates would come after long periods of time. There are times during the design process that require straight back and forth interaction as opposed to posting a message and waiting for someone to reply. Communication regarding CAD and simulation data reverted back to familiar tools like email and instant message services. Students would email data files and then discuss them over instant messages in order to optimize the design

While this is still a powerful method of communicating and collaborating, there is no record of these events since posting emails and message histories is inefficient. So while the wiki is useful in the early stages of a product design, it seems like its applicability for active collaboration diminishes as the project moves to latter stages as it requires synchronous or near synchronous communication for some aspects [5].

4.1.4 Team Centre Community in Auto21

One of the main industry representatives for this project was Unigraphics, a company that specializes in project management software packages. For this project one

of the collaborative tools used was Team Centre Community which is a product lifecycle management tool that is used in many companies for organizing their projects. None of the participants had any prior knowledge of TCC or its capabilities. TCC provided an online area where users can access and post all their information and add discussion threads. The reason this particular tool was chosen was that the chief principal investigators of this project wanted to use the Unigraphics NX package that was created for CAD collaboration. Since they understood that the CAD aspect of this project was not going to be necessary until further into the project they decided to start with TCC as part of the user interface was similar to NX and thus allowing for a smoother transition once NX was needed.

4.1.4.1 How Team Centre Community was used by Auto21

Once people began exploring the features of TCC many did not like the presentation and interface of the package appealing and so didn't use it.

4.1.5 Discussion of Auto21 Study

4.1.5.1 Discussion of Concept Maps in Auto21

The use of concept maps in this project was limited at the early stages of the project. One year into the project the participants were given a feedback questionnaire regarding their usage of concept maps. While the majority found the tool very easy to use they didn't feel a draw to concept maps. The maps that were created were because they were asked to use the tool. One student commented that "...I haven't really had the urge to use it (concept maps) on my own (i.e. I haven't come across anything and thought to myself that cmap would be perfect!)". Thus usage of concept maps in this project stopped.

4.1.5.2 Comparison of TCC AND TWIKI

Even though TCC was introduced before the TWiki it was the wiki that received the most amount of traffic and ultimately became the tool of choice for the Auto21

project. This section will discuss both tools and show why the wiki was more appealing to the project participant than the PLM package

Setup and Usage

Both tools required a significant amount of setup time before they were introduced to the students. The TWiki was introduced in 2006 and maintained at Ryerson University where one of the PI's acted as the dedicated administrator for the site, and TCC was maintained at Waterloo University and had a graduate student as its administrator.

Some of the first impressions that many of the students that used TCC was that they didn't know how to find information in TCC, and the folder organization system in place was very confusing. On the questionnaire about TCC, one student commented that 'I think the main turnoff was the format. Too many folders and subfolders. Too many places to post things. I was never really sure where to post my work.'

The other complaint was just with the overall presentation of the site. A big part of online collaboration comes from visual appeal. Since the majority of the communication will be through visual media the presentation of the information should be clear and conducive to quick assimilation. With TWiki the student had more control of where they wanted to put their work. If a particular page was insufficient for the information they wanted to present they could just create another page. They also had control of the layout and structure of the entire wiki allowing them create an atmosphere that was more attractive for them to work in. One student commented 'Generally, we keep it pretty neat and tidy, yet cheery. Maybe that sounds cheesy, but when I look at TCC, it's pretty boring.' This same sentiment was repeated when students were asked why they preferred using TWiki to Oddmuse. One student referred to Oddmuse as having a very 'amateur' look to it which discouraged him from wanting to explore the wiki further.

When the project switched from Oddmuse to TWiki there was a noticeable shift in the usage of the wiki. This shift was due in part to the more 'professional' look and feel of the site. It created an atmosphere that invited the students to delve deeper into the features that TWiki offered. Due to this new comfort with wikis, the team was able to

start creating wikipages and recording all their research. The new wiki gave them the freedom to layout all the information in a way that would make the pages more presentable for everyone to read and understand

One of the other advantages of the TWiki over TCC was that the student could add content directly onto the wikipage whereas for TCC they would have to create a text document and then upload it to the appropriate TCC folder. But even though you could add content directly it required learning the wiki syntax for the text editor. Oddmuse came with only a text editor and since this was the first exposure to wiki editing for the majority of the student it took them a while to get used to the syntax. They found that they had to spend more time editing their work than adding content to the page as they had to pay close attention to the formatting rules of the text editor. A simple example of this frustration can be seen here.

If the student wrote the following:

```
*Wikis are great for engineering collaboration
*Especially for *Early Engineering Design*
```

The wiki will render this as

***Wikis are great for engineering collaboration *Especially for *Early Engineering Design**

When the author actually wanted it to show as,

- Wikis are great for engineering collaboration
- Especially for **Early Engineering Design**

By not putting spaces after the first stars the wiki editor interpreted the sequence as something totally different. If this had been a large change to the wiki the author would have had to go through the entire document and hunt for the source of the error. This discouraged students from wanting to go through the effort of putting up their work or commenting on someone else's suggestions.

For a tool to be accepted as a collaboration medium it has to give the participants a feeling of ease in using the tool. The tool has to give the user the opportunity to focus more on the content of what is being communicated than the intricacies of the tool. One of the advantageous features of TWiki was the inclusion of a WYSIWYG. This would give the students a more familiar environment in which to add new content without having to worry about syntax rules of the text editor. While this was used in the beginning, more students abandoned the WYSIWYG for the text editor since they found that the text editor provided more options and versatility in how they wanted to present their information thus making it more readable for the viewers. Since TWiki was used more than OddMuse, but the WYSIWYG editor was *not* used, the students seemed to have become accustomed to the syntax of the text editor and found that they could perform certain functions faster than with the WYSIWYG. This may be connected to the familiarity with programming languages that most engineers learn during their education [51].

Engineering specialized PLM packages like NX from Unigraphics are focused on the collaboration of CAD work. While this is an important part of the engineering design the software only helps for those later stages of the process. PLMs do little to foster the early stages of design and promote the creative aspects of concept ideation and generation. Other design tools have to be used first and then linked to a PLM package for further improvement to the sharing of information [52]. Since wiki's can take on a variety of roles based on the needs of the user, wikis like TWiki have been used successfully as project management tools similar to the way PLM's have been used. This project management also extends to supporting early stage design collaboration [5].

The usefulness of TWiki diminishes once a project leaves the early design phase and enters the design for manufacture stage where engineers need to collaborate over CAD drawings. This is where a switch to PLM packages could be most beneficial. This switch was seen in the Auto21 project when it moved to a component design phase of the project and students were focused on CAD related collaboration. Here the use of TWiki waned and students began using email and instant messaging services for working within the team and then posting results of this collaboration on to the wiki.

Discussion Threads

The early stages of engineering design look into the broad aspects of the product, which requires a high level of discussion among the principal designers and the customer to clearly define the problem and the boundaries within which the design will fall. With either of these tools the designers can contribute their thoughts to a single location. This centralization of information also ensures that everyone has a common understanding of what the goals of the project [53] and can see all the work being done by other group members.

Both platforms could support discussion thread but TCC had a forum style feature within the package. Students could create a thread and then any comments could be added by other users, just like any other online forum. The problem with the discussion threads in TCC was that they were hard to find the individual threads. A number of times one of the students would create a thread but very few people would know about it and thus no discussion was had.

In TWiki the discussion threads were more time consuming as the forum style feel to the discussion page had to be created. Students would have to create a separate page for each discussion topic so that other group members can go in and add their comments. With a regular discussion wiki page, if someone wanted to add their opinion to the thread they would have to go into the text editor or WYSIWYG for that particular page, scroll down to an appropriate point in the discussion and add their comment. TWiki has a plug-in feature called *Comment Box* which the original author of the thread can add a single call command when creating the wiki page. Once rendered there would now be a text box at the bottom of the page where someone can add a comment without having to enter the text editor. Some wikis like MediaWiki [www.mediawiki.com] or Wikispaces come with their own discussion pages attached to each of the wiki pages so that there is direct discussion about the content of the page

Even though the creation of the discussion pages in TWiki took a little more effort they were used more often than with TCC because the students were able to find the discussion thread to a particular topic more easily as they were usually found within the subsystem page (i.e. discussion on power source was in *Power* subsystem page). It also helped that, in TWiki, any new comments would be registered by the notification system.

Notification

An important part of online collaboration, especially for distributed groups, is notification of changes. This was one of the main reasons why the students were not able to use collaborate with TCC. No one would know whenever anything new was added to the TCC site so discussion threads would be left unanswered.

For wikis there is a wikipage dedicated to listing out all the recent changes that have been made to a particular page as well as the author of this change. So should a person be interested in that change he/she can just go and view it and ignore the rest. TWiki also allows for email notification of changes. For example, if someone working on the *Chassis* system would like to know if there have been any changes to pages regarding the *Suspension* system. He/She would simply subscribe for email notification of just those specific pages. Then when ever a change has been made by the *Suspension* group to those wikipages the *Chassis* representative will be informed and could see if there is continuity between the subsystems. This allows for a more efficient use of time as a user does not have to waste time searching to see if something has been changed in a particular wikipage. This notification system led to greater usage by the distributed Auto21 groups as it gave an indication when other groups had done work.

Notification is also essential for promoting feedback in discussion threads. The notification system tells the entire group when a discussion thread has been created or responded to so that if the topic is of interest to them then they can go and provide their own feedback. An example of this can be seen in the Power Discussion from the Auto21 project. The thread was started by one of the HQP who posted a preliminary power requirement and battery sizing estimate. There was a lot of interest in this discussion as power was a critical factor for the design of an electric vehicle. The notification email was sent out to the group of registered users and prompted a response from one of the industry representatives of the project giving advice on other potential subsystems that require power and need to be considered as well as recommendations on battery types and brands. Subsequent notification of this feedback encouraged more input from other PI's and HQP thus allowing for a decision to be made on the type of power system going to be used.

Notification of changes can also be achieved through RSS feeds. This is done strictly through the browser and does not require the user to edit any of the TWiki pages. The resulting feed shows a list of all the recent changes made to the TWiki space in chronological order. This gave the participants a direct link to the changes within their browser thus allowing them to unsubscribe to the email notification as they were wary of having their inbox overloaded.

Security

Both packages required a login and password to access. TCC assigns an obscure login and password that is difficult to remember and has to be written down somewhere. While this may seem like a minor detail, it detracted some people from wanting to access the site. To add to this frustration, the site would request a login periodically when browsing the site.

Since TWiki is a wiki it was open for anyone to browse, while TCC was restricted to only authorized group members. On TWiki only registered users are allowed to add content to the site or change any of the existing information. . This will allow the wiki to track all the changes made by that user and tag all these editions. Now the changes page will list all the pages that were changed and will show who made the change and when it occurred. This is also used for the *Comment Box* plug-in by adding the name tag to whoever was logged in when a comment was added.

It should be noted that one of the drawbacks to comparing usage of TCC and Wikis in Auto21 is that they both provide the same basic functions. Once the group started using TWiki there was no reason to use TCC. Using both tools would have distributed the project information making it hard to find what people were looking for.

4.2 ME8101 study

In the winter semester of 2006, 17 graduate students from Ryerson University participated in a concept mapping exercise. This exercise was to be a practice run for the CDRN concept mapping workshop that was to occur at a later date. The exercise had two main goals. First, to observe any patterns in style and layout that may be attributed to engineers in particular. This would provide an insight into how engineers gather their thoughts and present them through a visual medium. Analysis of the maps may lead to recommendations that tailor concept mapping tools to support this thought process. The second goal was to explore the collaborative aspects of CmapTools and see how these engineering students worked together in a distributed scenario.

4.2.1 How was the exercise run?

The entire exercise was run over a 2.5 hour session in one of the computer labs at Ryerson University. Each terminal had the latest version of CmapTools installed and could connect to the CmapServer facility provided by Dr. Salustri.

To make the students familiar with CmapTools they were given a 15 minute tutorial on all the basic mapping functions and features that CmapTools had to offer so that they could customize their map in any manner they saw fit. Once everyone was comfortable with the software they were tasked with an exercise to create individual maps that answered the question 'What is Design?' The students were given 30 minutes to complete this exercise and were told that they were free to draw upon all aspects of their personal lives to answer the question, i.e. education, culture, experience etc.

This exercise produced 17 concept maps representing the view points of the 17 students. All the maps were categorized based on the types of layout features they exhibited to see if there was a predominant layout structure common to these engineering students.

After the individual exercise the students were divided into groups for 3-4 and tasked with collaborating on a single mapping space over the CmapServer to answer the same question. This was done to see if the collaboration between the parties will yield new ideas not found in the individual maps. Due to technical difficulties with the server

this part of the exercise was scaled down to see how pairs of students would collaborate. Even though the students were in the same room during the exercise they were instructed to only communicate with each other using the CmapServer facilities which included an instant messaging feature. Only 6 of the pairs of students were able to successfully create collaborative maps.

The last 30 minutes of the entire session was a discussion period where the students provided feedback on what they thought about concept mapping as a medium as well as their opinion on the usability of the online collaborative features of CmapTools.

4.2.2 How the Maps were analyzed

Each of the 17 maps created were categorized by layout style to see which style was most predominant. The six different styles that were observed were Hierarchy, Networked, Web Graph, Scattered Branch, Linear, and Cyclical.

- Hierarchy Pattern – has broad topics located at the top of the graph and then each subsequent tier of nodes has more specific information.
- Web Graph – Similar in progression to a hierarchy except the broad topic appears at the centre of the graph and the subsequent nodes spread outwards as based in a polar coordinate system as opposed to a Cartesian one.
- Network – highly interconnected nodes
- Scattered Branch – randomly placed nodes and branches with no discernable pattern and minimal interconnectivity between nodes.
- Linear – All the nodes appear in a sequential order
- Cyclical – Nodes arranged with some element of feedback to previous nodes.

Also the subsequent tier pattern was looked at for each map.

- Bloom – where the subsequent nodes would encircle the parent node.
- Line - where the subsequent nodes were aligned either horizontally or vertically

For the second part of the exercise each collaborated map was compared with the two individual maps that were created in the prior exercise to see how much content was contributed by each person and how much was new content contributed by their collaboration.

4.2.3 Individual Exercise Map Results

One of the principle goals of this exercise was to explore how engineers layout out their thoughts in a visual manner in order to customise future mapping software for these patterns. With concept maps the students were able to show how they structured their thinking and organized their ideas in a way that made sense to them. The maps that were generated from this exercise represented a number of different styles of pattern flow. For this exercise the problem question of 'What is Design' was chosen because of it was open ended. This would give the student the freedom to draw from all their collective knowledge, similar to when coming up with solutions to any kind of design problem. The question was deemed appropriate since all the participants in the exercise were from a graduate level engineering design course so they had some exposure to the concepts of design. Table 4.1 shows how each of the maps were categorized based on layout pattern.

The most common is the Hierarchy pattern occurring in 35% of all the maps. Each new level of information either showing greater and greater detail or a progressive step in a design process. There was one example, Figure 4.11, of a hierarchy where the student organized the nodes in a left-to-right flow as opposed to a top down one. The former style of hierarchy more closely follows the natural flow for reading a full document in most language (unlike languages like Arabic or Mandarin), top to bottom, and left-to-right. The latter style allows for more readability since each branch of the concept map is representative of a sentence and a written sentence is usually read from left to right. The next two most common layout patterns were linear, web graph and scattered branch, and the least used patterns was for cyclical and network structures.

One aspect of concept map layout that was interesting is the style that the students used when creating a subset from a particular node. The majority of the maps, 47%, had an element of linear subset patterns; a good example is in Figure 4.17. Another pattern found was a 'blooming' pattern seen in 17% of the maps as seen predominantly in Figure 4.12.

	Overall Map Pattern								Subsequent tier pattern	
Student	Networked	web graph	Scattered Branch	Hierarchical	Horizontal Hierarchy	cyclical	Linear		bloom	line
S1	X	X	X	X	X	X	X		X	X
S2										X
S3									X	
S4										
S5									X	
S6										
S7										
S8				X						X
S9				X						X
S10										X
S11				X						X
S12										
S13				X						X
S14				X						X
S15				X						
S16										
S17				X						
	1	4	3	6	1	1	4		3	8
%	5.88	23.53	17.65	35.29	5.88	5.88	23.53		17.65	47.06

Table 4.1: Layout configurations of Individual maps in ME8101 Study

Figure 4.10: Student 1 (S1)

Figure 4.11:Student 2 (S2)

Figure 4.12: Student 3 (S3)

Figure 4.13: Student 4(S4)

Figure 4.14: Student 5 (S5)

Figure 4.15: Student 6 (S6)

Figure 4.16: Student 7 (S7)

Figure 4.17: Student 8 (S8)

Figure 4.18: Student 9 (S9)

Figure 4.19: Student 10 (S10)

Figure 4.20: Student 11 (S11)

Figure 4.21: Student 12 (S12)

Figure 4.22: Student 13 (S13)

Figure 4.23: Student 14 (S14)

Figure 4.24: Student 15 (S15)

Figure 4.25: Student 16 (S16)

Figure 4.26: Student 17 (S17)

4.2.3.1 Discussion of Individual Map Exercise

Even though students were told that they could draw on any body of knowledge and experience to express their thoughts, most of the maps had content that was limited to an engineering scope. The maps included very technical aspects of the engineering design process, items like 'design requirements', 'constraints'. The exercise question, 'What is Design' was chosen so that students would have the opportunity to not only show their current understanding of 'design' in the context of their class but also connect this understanding to what they already knew about design from their personal experiences. It was hoped that this would give students diversity in their content thus allow for more thought to be shown in the layout structure of the maps as it may pertain to engineers.

Some students kept strictly to the methods and design processes taught in their graduate level design course and showed little to none of their own personal views on design. A few of the students were able to show connections with art and architecture showing the initial steps to looking beyond engineering, but that was the extent of that line of thinking. Novak attributes low connectivity among nodes in a hierarchy pattern to a poor understanding for the subject being discussed [4]. One possibility for the students' narrow view on the subject may be due to limited time given to generate the map, thus they did not have the opportunity to broaden their thinking to include other aspects of design.

From informal interviews with the students after the discussion sessions and correlating that with the maps they created, there may be a possible connection between the layout style and the background of the author. Some of the older students with a more regimented formal education tended to prefer a linear hierarchical pattern, while younger students would tend towards a more abstract and free form structure. Such a study would provide a very useful look at the whether culture or education has an impact on the manner in which an engineer expresses himself/herself.

While this was the first time the students used a concept map to the portray information, many of them said that they could see how effective this tool would be in

their designing activities. Students would approach this author seeking advice on using concept maps for some of their projects in other engineering courses.

4.2.4 Collaborative Exercise Map Results

The second aspect to the concept mapping exercise conducted by students of ME8101 involved collaborating with each other over a server to see how well pairs could work on a single map which represented the combined opinion of two of the students. Due to these technical difficulties only 6 pairs of students were able to produce maps that they had collaborated on. Two distinct trends of contribution were seen in these maps first being an even contribution by both parties and the second being a dominance of one student over the other. The collaborated maps were color coordinated so that yellow and blue nodes would represent contributions by each student and the green nodes were new ideas that were brought up through their collaboration.

The first style showed an even contribution by each of the students for the content that was shown in the combined maps. When looking at the individual maps that the students had made and compared it to the collaborated map it was apparent which elements belonged to which student. Looking at the individual maps created by Student 1 (Figure 4.10) and Student 2 (Figure 4.11) and at the map of their collaboration, Figure 4.27 one can see the nodes that describe what happens when design is 'done right' or 'done wrong' are from the map of S2, while elements that describe design as a process to create product to solve problems are given from S1's map. Very little of the map seems to be new ideas that the two of them came up with together. If we look at the layout of each of the individual maps, S1 is a structured hierarchy pattern with a definite flow from top to bottom and S2's map has a horizontal hierarchy pattern which flows from left to right, each one unique and clearly laid out. The combined map was a very haphazard scattered branch pattern which flowed from the central concept, 'Design', outwards in every direction. None of the linearity of S2's map was transferred into the new map.

The other distinct style showed a dominance of one student over the other. The collaborated map would only show elements that were included in one of the individual

maps and the remaining elements would be new. Two examples that show the extremes of this style are seen in Figures 4.28 and 4.29. In the Figure 4.28 example the collaborated map had about 50% of its elements contributed by S8 (See Figure 4.17), only 10% of the content presented can be found in S9's individual map, Figure 4.18. The rest of the elements were new items that were contributed from the collaboration between S8 and S9. The other example of this style is seen in Figure 4.29 where 75% of the elements were contributed by one student, S3 (See Figure 4.12) and the remaining small portion was a collaboration of the two students as these elements were not present in either of their individual maps. So none of the original ideas from S10 (Figure 4.19) were used in their team map. These various forms of interaction showcase the different roles that emerge during the collaboration process. In the first style both students in the pairings are 'actors' so there is an active involvement from all parties to contribute to the content of the map.

In the second style one of the students took over the role of actor while the second student would take on a less involved capacity. Usually in situations where one student becomes a predominant actor the other student would take the role of 'observer/critic' where he/she would sit back and allow the actor to record all the information but would actively participate in the discussion of the content being recorded. The content of the maps suggest that the student did nothing to actively participate like an actor. Since only a small portion of the map was new content this suggests that there was only communication and mutual input by both students for that small part of the map. While there was some input by this student it does not fit with the role of an observer/critic.

Figure 4.27: TEAM SIS2

Figure 4.28: TEAM S8S9

Figure 4.29: TEAM S3S10

Figure 4.30: TEAM

Figure 4.31: TEAM S11S16

Figure 4.32: TEAM S5S15

4.2.4.1 Discussion of Collaborated Map Exercise

From the synchronous collaboration exercises the most common complaint by participants during the feedback session was the lack of control for making changes to the mapping space. There was a feeling of confusion due to the sudden emergence of new information while they themselves were making a change. To solve this problem the 'baton' solution was recommended, similar to the 'key' possession in the Patras Exercise [38]. The 'baton' would allow only one person to have edit privileges at any one time. This will reduce that feeling of multiple people talking at the same time. Controlling the edit privilege should promote more communication between the parties to explain their thoughts so that they may be recorded, or to request control of the 'baton' so that they may make the changes themselves.

While an offsite synchronous collaborative session attempts to recreate the face-to-face meeting environment in a virtual setting there is still a need for a feature like the baton control. In face-to-face meetings there is a perception of 'free for all' where all the participants in the meeting would continuously contribute their ideas, but even in these sessions there is still only one person speaking at any one time, if everyone spoke at the same time no one would be heard and no work would be accomplished. Physical presence and gestures give indications as to when someone is going to speak, thus everyone else stops talking and pays attention to that one person [37]. The baton control in this virtual setting takes the place of these physical cues in the real world.

One of the downsides to baton control as seen in the Patras exercise was the tendency of one individual to monopolize control of the map by not giving up the key. One possible solution would be for the group to designate an administrator for the session so that he/she has the power to pass the baton to someone else to provide input. Even with this system there is always the chance that the administrator will become the one that monopolizes the baton. Another possibility would be to have the CmapServer run in conjunction with a teleconferencing service like Skype. This would provide an audio presence for individuals to gain the attention of the rest of the group and request for the baton as well.

While dominance in a concept map can be curtailed by a baton control, the allowance of such dominance is accounted for by teamwork and group dynamic. The

concept map is only a representation of the work created by the group. If there is dominance in the structure and content of a map from just a single individual it shows a lack of group interaction. The concept map can not change if a team works well or not, but it can make this dominance become obvious so it can be addressed by the group, if it needs treating. Such an observation of dominance could not be seen if a design was strictly in a text documents as the contribution by each individual is not blatant.

While dominance by one individual can lead to a map that is skewed to a certain layout, but again this is a matter of teamwork. Ultimately, if everyone in the group deems the map that is produced in the collaborative session to be a good representation of the project then whether there is evidence of dominance is irrelevant.

The informal discussion period at the end of the exercise provided valuable feedback on the usage of the tool. There are some limitations to the amount of information gathered as an informal session doesn't necessarily get the opinion of everyone in the group but rather those that are more vocal. A better information gathering technique would have been a questionnaire given to all the students after the exercise was run to get everyone's opinion.

4.3 St. Michael's Hospital Project

In 2001, Akram Kamal El-Ashy [53] presented a graduate thesis to the Department of Mechanical and Industrial Engineering at Ryerson University on the use of UML and SADT to create a business model for the radiology department of St. Michael's hospital. At the time St. Michael's Hospital was making a big push towards a paperless environment to make day to day operations faster and more efficient. El-Ashy's thesis highlighted areas which would improve the workflow of these operations by mapping the process in UML and SADT. Since St. Michael's used the same business model for every type of radiation therapy El-Ashy's work focused on the Ultrasound modality and would be able to mirror its results for other operations. After looking at the various UML diagrams produced in El-Ashy's work it was determined by this author and his supervisor that this would be an interesting opportunity to compare the UML visualization techniques to those of concept maps.

4.3.1 What was done?

A single concept map was constructed using the procedures and guidelines outlined in El-Ashy's thesis. The map was created by two French students from the IFMA program, Pierre Francois and Kevin Bigot, under the supervision of this author and Dr. Salustri. The concept map outlined the entire radiology process starting with entry into the hospital till return to the recovery ward. This map was then compared with the UML diagrams produced by El-Ashy to see if the concept map was able to capture the same information but in a more readable fashion. Once the concept map was complete it was presented to El-Ashy and Dr. Peter Pille, El-Ashy's supervisor, to get their feedback on the map. Unfortunately this work was not able to be presented to St. Michael's Hospital since the contact there had moved on.

4.3.2 What was done by El-Ashy

(All the diagrams from this section were created by Akram Kamal El-Ashy).

El-Ashy used 6 diagramming techniques to create his business model, 5 of which were based on UML diagrams and 1 using SADT.

- ***Behaviour diagram*** outlines the distribution of workload and shows a very broad overview of where in the process every actor belongs. These diagrams show a single static view of the system. [Figure 4.10]
- The ***Use-Case diagrams*** give a preliminary outline of the process and where the actors come into the process. The pattern is meant to show all the sub-processes in the business model and give a clear description of how each actor fits into each process. [Figure 4.11]
- ***Activity diagrams*** map the flow of control within each sub-process showing the operation from one object to the next. [Figure 4.12]
- The ***Sequence Diagrams*** emphasize the order of operations for each actor. [Figure 4.13]
- The ***Business Diagram*** embodies all the information that was described in all the previous types of diagrams showing the collaboration between all the different objects in the model. [Figure 4.14]
- The ***SADT pattern*** breaks up each step in the business process and details the four major inputs and outputs from each step (according to the ICOM model). [Figure 4.15]

El-Ashy created a comprehensive set of diagrams that outlined every aspect of the business process of the Ultrasound procedure and was able to find a number of areas to improve the efficiency of the process and eliminate unnecessary steps.

Ultrasound Behavior Pattern

Figure 4.33 : Behaviour Diagram

Ultrasound Use-Case Graph

Actors:

- Sonographer/Resident on call
- Sonographer
- Patient
- Transcriber
- MD (Medical Director)
- Patient Nurse
- Radiologist
- Radiologist (Resident on Call)
- Porter

Automated Use-Case 1 (Sonographer/Resident on call):

- Log in (AUC-01)
- Update MWL (AUC-13)
- Generate requested images (AUC-14)
- Generate additional images (AUC-15)
- Push images into PACS (AUC-16)
- Execute ultrasound exam (AUC-17)
- Assist in setting the exam (AUC-18)
- Review FX films (AUC-19)
- Save data (AUC-23)
- Log out (AUC-22)

Automated Use-Case 2 (Patient):

- Generate Appt & Prep Sheet (AUC-04)
- Print Appt & Prep Sheet (AUC-05)
- Identify Patient (AUC-06)
- Generate new patient in ADT (AUC-08)
- Inform ultrasound exam unit (AUC-07)
- Print out hospital card (AUC-09)
- Generate ultrasound exam order (AUC-10)
- Rebook ultrasound exam order (AUC-11)
- Save data (AUC-03)
- Log out (AUC-02)

Automated Use-Case 3 (Transcriber):

- Log in (AUC-01)
- Transcribe Final Report (AUC-24)
- Save data (AUC-03)
- Log out (AUC-02)

Automated Use-Case 4 (Radiologist):

- Log in (AUC-01)
- Review ultrasound images (AUC-20)
- Review additional ultrasound images (AUC-21)
- Execute ultrasound special exam (AUC-22)
- Record final Report on workstation (AUC-23)
- Save data (AUC-03)
- Log out (AUC-02)

Index:

- AND:** Association Link
- OR:** Use-Case/Process
- Note:** Actor
- Collect Node:** Note
- Extends:** Uses

Figure 4.34: Use -Case Diagram

Ultrasound Radiologist Sequence Diagram

Figure 4.36: Sequence Diagram

Ultrasound Scheduling Process Activity Diagram

Figure 4.35 : Activity Diagram

Figure 4.3.37: Business Model Diagram

Figure 4.38 : SADT Diagram

4.3.3 Concept Map Adaptation

By color coding each node this showed where in the process each member of the staff was required. This simple visual application accounts for all the information provided by the Behaviour Diagrams in UML. The text within each node shows the action that takes place for that step. So now the node has the actor and the action which is the information represented in the Use-Case diagrams. Since the concept map shows a process flow through each phase of the ultrasound procedure there is a natural sequence to this order. As each step has a actor designation the sequence of each staff member is also made evident. This showcases element from both the Activity and Sequence diagrams. So it can be seen that the single concept map was able to capture much of the information presented in a number of UML diagram with only the paperwork designations being left out.

Looking at the UML diagram of the overall business class diagram, for readability there does not seem to be a point to 'start' reading the map. All the nodes of information are haphazardly located throughout the diagram with multiple links traveling all over the map with no intuitive flow. The other downside of a map of this style is following the path taken by actors. As links moves from one node to the next there is no evidence as to which of the actors are moving with the flow. With the concept map there is a clear path through each sub process and it is clear who is needed at each step within these processes.

El-Ashy used SADT diagramming techniques to compliment the information provided in the UML diagrams. The business class diagram outlined the overall process of the ultrasound exam but the SADT diagrams were used to show a more detailed look of every step.

From examining the overall SADT diagram for the whole process the layout of the diagramming technique gives an impression that the steps boxes are part of a sequence when in fact some of the boxes represent different procedures that occur depending on a decision by the medical staff. SADT does not make it apparent that at an early stage there is a decision point which will result in one of many procedure paths. With the concept map there is a clear distinction that after the registration phase then there is a decision of which procedure to take. Even within each procedure there are

small decisions that result in two possible paths, something that is not seen in the SADT diagrams. From the concept map there is a definite indication of where each of the staff members are required. It also gives an indication as to the movement of the patient from one hospital room to the next. With the color coding there is a better understanding of how involved each staff member is in the whole process. UML is only a black and white based system of visualization while newer visualization tools, like CmapTools and Mindjet Mindmanager, use color for variability which eliminate the need for some of the inherent complexities of UML diagramming techniques.

“Experience has shown that when people have a perception that something is difficult to understand (like UML) they won’t understand it; however when the same information is presented as a simple picture, they understand perfectly!’ [9, pg 9]

From feedback by El-Ashy and Dr. Pille, they both agree that the concept map provides a cleaner overall visualization to the information being presented even though it lacks some of the detail presented in the UML documentation like the internal paperwork designations. Possible implementation of these concept maps in the St. Michael’s Hospital setting would be the use of the overall map (Figure 4.39) for everyone to have an overall impression of the whole process. The map would have to be poster sized in order to make all the nodes legible. This large map can be broken down into sub maps that show only the operations of specific personnel. These specialized maps can be made to fit on just a single letter sized sheet of paper since they would have only specific information.

US Receptionist
US Sonographer
US Radiologist
Nurse
Patient
Transcriber
RIS

Figure 4.39: Ultrasound Process at St. Michael's Process

4.4 CIHFR

In December 2006 a number of researcher came together to explore the possibility of combining various fields of research study so that they may offer a graduate level degree in human factors. Each researcher would introduce the areas of human factors that they were working in and see if there were any other researchers working in similar or compatible areas so that they may work together. It was decided that a concept mapping session would be a valuable process to help map the various streams of research.

4.4.1 What was done

The meeting would be run in a *stenographer* style, instead of having everyone become familiar with concept maps and accessing a server due to the busy schedules of the researchers. In this scenario a large projection of a concept mapping workspace will be displayed in front of the group. One person would be designated as the *stenographer* and would have complete control of the concept map. The whole group would relay their suggestions and ideas to the stenographer and he/she would record them onto the concept map for all to see. As this author was the stenographer for this meeting and observed how the participants interacted with each other while using the concept map as a guide.

4.4.2 Discussion of CIHFR Maps

Prior to the meeting the main organizer of this meeting had created a starting map that showed her research interests and so this was used as a jumping off point for discussion. Very quickly the map grew both in size and interconnectivity. As the meeting progressed many of the other researchers added their own input and found possible links between various streams that were not as apparent before which was in line with the ultimate goals of the meeting.

Having the concept map up at the front of the meeting was an extremely effective tool in stimulating various discussions stemming from the content of the map. Figure 4.12 shows the preliminary map that was produced by the main organizer of this project. The map evolved into the one shown in Figure 4.13. From looking at the map we can see that the use of the concept map allowed the group to identify and explore aspects that

were beyond the immediate scope of human factors. In the upper portion Figure 4.13 we can see a large discussion on the communication of knowledge and information, in the lower portion there is a mini side map that pertains to business considerations something that must be kept in mind for future discussion.

Even though the meeting was only 3 hours long there was significant progress made because there was little lag in the discussion. The only time the meeting slowed down in pace was when a researcher had to explain to the stenographer how their input was to be represented, but following this the discussion picked up again.

A more efficient way to have run this session would have been with group edition style. This method requires that all the participants be seated in front of their own computer terminal from which each member can access the same map over a server facility. Concept mapping software has very basic interface so it would not have taken long for all the participants to become familiar with the features of a software package like CmapTools. This way each member would not have to waste time explaining themselves to a stenographer, they can make the editions themselves both in terms of style and content. This would also reduce and even eliminate that small lag between discussions.

Figure 4.41: CIHFR Concept Map Post-Meeting (created by CIHFR group)

4.5 CDRN Concept Mapping Workshop Test Exercise

In early 2007 a group of individuals from a number of institutions across Canada came together to organize a workshop under CDRN, regarding concept maps and collaboration. This workshop was planned in conjunction with representatives from Simon Fraser University (SFU) in British Columbia, École de Technologie Supérieure (ETS) in Quebec, University of Toronto (UfT) and Ryerson University here in Ontario.

The experience and suggestions from the ME8101 activity were used to streamline the CDRN workshop so that the same problems could be avoided and so the productivity could be increased and the maps produced could have more depth.

The purpose of this workshop was to showcase as well as explore the power of concept maps and how they can be used in a collaboration setting. It is hoped that this workshop would attract people from various areas of design research, not strictly engineering or architecture, as well representatives from industry in an effort to see how concept maps can be used to collaborate across disciplines.

This endeavour had the potential to exercise the power of CmapTools as it had participants that were truly geographically distributed as opposed to localized in a computer lab. It was very apparent that the server used in the ME8101 exercise was inadequate from the many technical difficulties and lag in refresh rates. Dr. Maya Engali from SFU was able to secure one of the servers at her institution that met the technical requirements in order to run this workshop.

In May of 2007 organizers from the four schools came together to test out the facilities at their disposal in order to better plan schedule of events for the main workshop. Since SFU, ETS and UfT had AccessGrid capabilities it was decided to try a videoconferencing session in conjunction with Skype for audio conferencing. This worked very well with very little lag and allowed each of the school to be able to view each other. The synchronous audio conference allowed for a better discussion than with instant messaging. Now the collaborative concept mapping software could be explored more effectively since it was running on a faster server that could handle the input of multiple users and was also using the new CmapServer software. Thus the three schools started exploring all the features of the new server to find ways to resolve all the

problems found in the ME8101 exercise. Most of these problems were solved with the use of the dedicated server as now there was an almost instantaneous rendering of the map on all the screens. Unlike with ME8101 all the nodes and links were shown on all participating screens in the instant that they are created. It also allowed for more participants to join in on the same map as now people from all three locations were able to edit the same map, as opposed to only the pairs.

Looking back to the ME8101 exercise there was a number of students that felt that having nodes pop out of nowhere or suddenly move felt very distracting and both parties editing the same area at the same time was akin to two people talking at the same time. With the latest version of the CmapServer each terminal that is invited into the collaboration session is given a unique color so that whenever they try and add a node their presence is shown on the other screens by outlining that node. This allows the other participants to see which area of the map is being edited and by who so they can avoid it long enough for the editor can show their point. Unfortunately this feature has an 'interrupt' action that is built in. As one person is adding or editing a node another person can 'grab' that node mid edit and take control of it without having to ask permission from the one who was originally editing. It is uncertain why this feature was included but for a collaboration setting there would have to be a certain level of respect to not grab control from someone else without notification.

The newer versions of CmapTools also have a recording element which can be very useful for collaboration sessions. As a session takes place the recorder will make an account of every step change made to the map including editions of nodes, links, backgrounds and color. The recording is saved as part of the map and can be accessed by anyone who is authorized to view the map. This is useful for anyone who would like to go back and view the development of the map in case there are ideas that were discarded that are worth a second look.

During the testing session a few interesting observations were made. Past usage of concept maps has been to either represent some engineering related subject or had been created by someone with an engineering background. Dr. Filippo Salustri from Ryerson University's Department of Mechanical and Industrial Engineering found the simplicity of the layout offered by concept maps to be more appealing. In this test

session a few of the participants from the other schools were from non-engineering fields and commented that they found the graphical features of the program more interesting than the visualization tools. With CmapTools it is possible to place an image as the background of the whole map and then create the concept map on top of it. Or one can put an image as the background of a single node. Dr. John Danahy, of the University of Toronto Department of Architecture, Landscape and Design, found this could be a useful application for landscape architecture as it would help to plan land designations. Based on these comments there may be a distinction between which aspects of visualization are favoured across disciplines. In order to study the variability of style across disciplines the actual workshop should include a demographic survey to see if there is any correlation between style and layout with aspects like education or culture.

As this workshop is going to be held over a number of days, this will give the participants more time in the collaboration sessions to create a map that has more detailed content and structure. With the help of the dedicated server more participants may join in on collaborative sessions without slowing down the refresh rate and thus productivity of the session.

CHAPTER 5: RECOMMENDATIONS

This section will discuss recommendations for the improvement of concept mapping software packages and wikis. These recommendations are for improvement of the usage of the tool as well as its capability for distributed collaboration. Many of these recommendations are based on the feedback given in each the 5 studies discussed earlier as well as personal interactions with the tools.

5.1 For Usage of Concept Mapping Software

5.1.1 Styles Menu

In the current version of CmapTools there is a common styles menu pop-up box that appears to show all the various edit options available for the concept map. Within the box are four tabs representing each editable aspect of the map i.e. Font, Object, Line, Cmap. When using CmapTools the styles box can be placed anywhere in the screen and as the mapping space is manipulated the user must mouse over to the box to select the appropriate option. Too much time is spent on scrolling to the menu box, selecting the tab and then choosing the edit option. This scrolling action takes the author's focus away from the content of the point of interest as they have to move their eyes to the Styles window.

Since CmapTools is a very basic visualization tool there are only a handful of features that require editions. And each feature has only a few edit options. To improve the efficiency of the tool, these edit options should be made available at the point of interest. So, if the user selects a node then the only edit options needed are the Object options for color, shape, shadow, line (color, style, thickness), and background. While editing the text only the Font options are required. This will reduce time wasted scrolling and searching for the needed option thus allowing the author to focus on expanding the content of the map than editing it.

5.1.2 Nested Nodes

Nested nodes are used to show more detailed content regarding a specific node [54]. In systems architecture design they are useful in showing the sub systems within each system node. In their current condition when a nested node is expanded it covers the immediate area, as seen in Figure 5.1a and b. In doing this some of the connectivity with the surrounding nodes is lost as the links are not apparent anymore. One possible improvement would be similar to the method used in Mindjet Mindmanager, another visualization tool for mind mapping, where when a nested node is expanded the surround nodes are *pushed* out of the way. By doing this the links that connected to the nested node are retained, so that relationship is still visible, as shown in Figure 5.1c. One of the drawbacks of this is that with the surrounding nodes being pushed out of the way the layout of the map will be disrupted.

Figure 5.1 (a) showing nested node before expansion (top left). (b) Showing nested node covering other nodes (top right). (c) Expanded node pushing out surrounding nodes (created with CmapTools)

Another option that might be feasible would be a zoom in view of the nested node. Instead exploding the desired node if the program could zoom in and allow for the boundary of that node to become a mapping space, this would be a better visualization. A similar concept to the Zooming User Interface proposed by Nathan Eng [55]. This would emphasize the notion that this sub-map is on a subsequent tier of information. A sub-map would allow for a clearer break down of how the incoming links are used within the node. In a systems architecture sense it would allow for a second level architecture to show how any energy, mass, information is transformed with a particular system node.

Another small improvement for nested nodes would be to include the annotation from the collapsed node in the expanded node without having to make a separate node within the nested node. When looking at Figure 5.1a and 5.1b the original annotation of ‘Engine’ is lost once the node is expanded.

5.2 For collaboration with Concept Maps

This section will look at ways to improve a concept mapping software to make it more conducive for collaborative work.

5.2.1 Version Control

As mentioned previously, the most efficient way to evolve a concept map would be if everyone contributed their ideas to a common map. Unfortunately once a map is edited and saved any information that was deleted from the previous version is now lost. With a version control system in place similar to the one used in wikis, a design group has the option to revert to a prior version of the map should the need arise. Such a system would also keep a record of who made what revisions so that if further elaboration is required then they know who to ask. In the current CmapServer system one would have to dig through the gigabytes of server log data to find out who made what editions and when they made them.

5.2.2 Notification

In conjunction with *Version Control* it is important that the rest of the design team be notified whenever there has been some kind of change to any of the maps. This is important for asynchronous collaboration as it lets everyone know when progress has been made and encourages more feedback from the rest of the group. This might lead to faster and more effective feedback similar to what was seen by the participants in the power system discussion on the Auto21 wiki.

5.2.3 Baton Control

From the synchronous collaboration exercises that have been shown, the most common complaint by participants was the lack of control for making edits to the mapping space. There was a feeling of confusion due to the sudden emergence of new information while they themselves were making an edit. To solve this problem the 'baton' solution was recommended, similar to the 'key' possession in the Patras Exercise. Every synchronous collaborative session would allow only one person to have edit privileges at any one time. This will reduce that feeling of multiple people talking at the same time. Controlling the edit privilege will also promote more communication between the parties in explaining their views so that their views can be recorded or requesting control of the 'baton' so that they may make the editions themselves.

5.3 Improvements for Wikis

5.3.1 Editors

While the WYSIWYG is a powerful learning tool for beginners to get started using a wiki it is limited in its capabilities. Most WYSIWYG's are not true to their name in that the editing version is never an exact match to the rendered page giving an inaccurate representation of what the final rendering will be. In the Auto21 project as users become more familiar with wikis and the text editor they seem to prefer the text editor. This may be because some operations are easier to handle in a text editor than with the word processor like interface. For example, to make a word bold the author

would simply have to put a star in front and behind the word while with the WYSIWYG it requires scrolling to the word, highlighting it, scrolling to the menu and selecting the bold icon. This forces the author to shift his focus from adding content to the page to worrying about style, where with the text editor the desired output is only a few keystrokes away.

One of the drawbacks to wiki syntax is that it does require some learning. There is nothing intuitive about it, which was why there was some reluctance by Auto21 to use wikis as it required a push for people to learn the syntax in order to use wikis to their full potential.

Unfortunately if the author decided to use another wiki, it would require the learning of yet another set of syntactic rules. There should be a universal standard set for wiki syntax but this is one of those on-going debates as to what notation is most efficient and intuitive to use. [51]

For wiki text editors it would be ideal if the editor was a closer representation of the actual page. If the editor was a combination of text editor and WYSIWYG then a user can still use wiki syntax for quick strokes and still have the options of a WYSIWYG for more complex items.

Another improvement would be if the page was rendered as the user input data. As a line of text was written the wiki could recognize the style that is being requested and render it on the fly. For example, if a person write '%TOC%' at the top of the page to indicate a call for a table of contents. Instead of it staying as a line of code in the edit session it can automatically be shown in its rendered form. As a new subheading is added the wiki can recognize it and update the table of content. The same can be said for links to either a wiki page or a website. Once the site address or wiki page is written then that can automatically be set as an active link. An editor like this would give the author a clearer picture of what the final product will be like and allow him to spend more time on adding content than worrying about how its going to look in the end.

5.3.2 Discussion Threads

Even though the threads were adequate in promoting discussion there was too much effort in setting up a thread. A page would be set up for each discussion section

and then the original author would have to use the text editor to set up his question and then add the Comment Box call. For multiple threads, the question would have to be set up on the initial discussion page and link to a separate page to record the interaction. The Auto21 participants found that it took too much effort to set up new pages which resulted in all the discussion occurring on the same thread.

There should be a built in forum style discussion board that will automatically allow the user to create threads on various topics so that items are separated and easier to find. This has been a standard on *Wikispaces* and *MediaWiki* and should be adopted by all wikis.

5.3.3 Concept Map Guide to Wiki

As the Auto21 wiki began to grow and use large numbers of pages it became harder to navigate them. Some pages were buried in sub-page after sub-page, thus making the information hard to find and forcing the user to waste time hunting down the desired page. Thus a guide would help users see the overall structure of the Wikispaces and easily find the page they are looking for. A logical choice for the guide would be a concept map [56]. If both technologies worked together this may be a product management tool that accommodates all types of collaboration and still keep the creative aspect of early engineering design. The concept map can layout the structure of the project whereby each node could represent a wikipage, similar to the webmaps. By using mapping software like CmapTools, it will give the design team some flexibility in how the map should be laid out and presented as opposed to the rigidity of the webmap feature in TWiki. Any nodes created on the concept map will automatically generate and link to a wikipage based content of the node. With the new visual aid navigation of the wiki will be easier and allow the design team to plan more effectively.

CHAPTER 6: FUTURE WORK

6.1 Face-To-Face Meeting with *Group Edition*

From looking at the CIHFR and JTA workshop meetings it can be seen how concept maps have been used to guide a face-to-face meeting by providing a central point of focus. Both of these examples used the stenographer style of collaboration. A future concept mapping session, possibly with the CIHFR group, should focus on the *group edition* method. Such a session would examine the differences in group productivity as compared to the stenographer style that was used in the previous CIHFR meeting.

This method also has the added possibility of showing a different layout that has not been seen, as there are now more diverse individuals working on the map, thus allowing it to evolve to something unique to them. As opposed to something structured by a formal concept mapping 'expert'.

6.2 Synchronous Collaboration exercise

The ME8101 study should be repeated but with a dedicated server that can accommodate more of the synchronous participation. By improving the exercise based on the lessons learned from the first exercise this will provide a better set of maps to be analyzed. By increasing the time restriction on the personal maps will give the engineering students more opportunity to move beyond their 'classroom' thinking mode and produce maps with a little more diversity and depth of thought. One area of interest would be to give a demographic survey to see if there is a correlation between a user's background and their style of mapping. The previous exercise has focused how concept maps are used and their style of layout. The next exercise should focus on a quantitative analysis of nodes and crosslinks, accounting for meaningful links. Such an exercise was beyond the limits of this study, but would provide valuable information. The collaborative ME8101 study should be run again to look further at the various roles that emerge during the collaboration and the group dynamics between these actors.

6.3 Cross Discipline Layout Style Comparison

In order to see if engineers have a distinct layout style for concept maps, there needs to be a comparison with the layout style of representatives from other disciplines. The CDRN concept mapping workshop will bring together academics and industry representatives from various fields allowing for a comparison of different layout styles. The workshop can also look into the group dynamics of distributed groups with different disciplines.

6.4 Group Dynamic

Part of the reason for some of the lag in collaboration at the beginning of the Auto21 project was because the group asked to collaborate together had no prior interaction with each other. Geographically dispersed teams lack any social interaction with each other which can be an asset when it comes to resolving disputes within the group [34]. An exercise should be run to see if group familiarity affects collaboration in a distributed setting.

CHAPTER 7: CONCLUSION

This study was done to find out how concept maps and wikis can be used to help distributed engineers collaborate, especially for the early stages of the engineering design process.

In the Auto 21 project the use of concept maps was very limited. While there were some maps created and iterated as the project progressed, for the most part the participants did not see how concept maps could help them in their design endeavours. The wiki was a more successful collaborative tool for the Auto21 project. The initial experience with wikis wasn't too favourable as seen with the lack of use of Oddmuse, but once they began using TWiki the wiki became the main collaborative tool of the project. Even though the TWiki was adopted and used frequently there was still a initial push that had to be given for the participants to use the wiki. This was because there was nothing intuitive about the wiki detracting the students from exploring the wiki out of simple interest. Once all the participants were experienced with the wiki then it became the main platform for file sharing, information storage and discussion. The wiki's simplicity and customizable layout made it the preferred choice over commercial PLM packages for the Auto21 participants.

Concept maps are meant to communicate a specific amount of information not just with the content of the nodes but also with the structure of the map. From the ME8101 study it was found that the majority of engineering students that participated tended towards a hierarchical structure when it came to presenting their thoughts.

The St. Michael's Hospital study showed how concept maps can be a clearer visualization than an accepted diagramming technique, namely UML. Even though the concept map that was created lacked a little of the detail contained in the original set of UML diagram, there was a consensus between this author and the authors of the St. Michael UML diagrams that the concept map presented a clearer idea of the whole ultrasound process.

The CIHFR meeting showed that concept maps may be used as a focal point in face-to-face collaboration to promote group debate and negotiation of the content of the nodes and the relationship with other nodes.

Wikis have been shown to be useful as a project management tool as well as an asynchronous collaboration tool for engineering related work. There is still more work to be done to see if there is a particular style for concept maps that is predominant among engineers to better facilitate collaboration.

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GLOSSARY

Auto21	The Automobile of the 21 st Century. A national initiative by the Canadian Network of Centres of Excellence to fund various research projects pertaining to automobile design and development
CAD	Computer Assisted Design.
CIHFR	Human Factors research group based at Ryerson University.
CmapTools	Concept mapping software used predominantly in this thesis
CmapServer	Server facility for CmapTools. Used for online collaboration and map storage
HQP	Highly Qualified Person. Title for student participants in Auto21 projects
ME8101	Advanced engineering design course for graduate students offered at Ryerson University
NX	Commercial PLM package by Seimans that specializes in CAD sharing
Oddmuse	Initial wiki used by Auto21 participants
PI	Principal Investigators. Title for supervisors on Auto21 projects
PLM	Product Lifecycle Management. Software package for organizing businesses or projects
RSS	Really Simple Syndication. An RSS feed is attached to a web browser and shows a content summary of the website.
SADT	Structured Analysis and Design Techniques
TCC	Team Centre Community. Commercial PLM package provided by Unigraphics Inc.
TWiki	Wiki used by Auto21 participants
UML	Unified Modeling Language
WYSIWYG	What You See Is What You Get. An alternative text editor in wikis.